Numerical Modelling of Wave Overtopping in Maritime Porous Structures

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Summary

This thesis was focused on the study of the overtopping phenomenon at maritime porous structures through the application of a numerical model AMAZON, empirical formulations and neuronal networks to a case study – West breakwater of Albufeira's Fishing Harbor. A sensitivity analysis of the flow parameters in a porous layer was performed in AMAZON. A comparison between AMAZON and IH-2VOF (numerical model) [1] results was made to adjust the parameters involved. It was concluded that porosity followed by interface permeability in a porous layer had the main influence on the overtopping. AMAZON should be calibrated when data field are available.

Keywords: *Overtopping; Porous structures; AMAZON model; Empirical formulations; Neuronal network.*

1 INTRODUTION

The study of the performance of porous maritime structures includes the assessment of wave overtopping along the same. Measurements of wave overtopping can be directly done in the structure with appropriate instrumentation, or can be tested by observing and measuring the structure in a physical model. However, it has to be taken into consideration that these measurements will always have associated costs. Therefore the use of a physical model will represent a significant extra cost in the total value of this type of engineering undertake.

The study of the overtopping phenomenon in the West breakwater of Albufeira's Fishing Harbor – the case study – used empirical formulations, artificial neuronal networks and the numerical model AMAZON. The tools used will be briefly described in the next Chapter.

The empirical formulations used in this study are the following:

- The methodology suggested in the "old overtopping manual" from United Kingdom [2] based on Owen's empirical formulation (1980) [3];
- The NEW methodology recommended on the "actual overtopping manual" [4], whose calculations were performed on-line (http://www.overtopping-manual.com/calculation_empirical.html).

More recently another calculation tool based on physical models measurements has been developed. This tool, NN_OVERTOPPING2 which is based in 700 neuronal network analyses, is also proposed on the "actual overtopping manual" [4]. Its database which consist of 950 tested structures and over 10 000 tests is available online.

This study presents a sensitivity analysis to porous equations parameters used in the numerical model AMAZON in prototype and scale 1:30 with regular waves. Parameters were adjusted through a comparison between mean wave overtopping discharge obtained with the numerical model AMAZON and IH-2VOF [1], due to the impossibility of validation with data field. The results acquired from AMAZON were done after an adjustment of the parameters and using irregular waves – JONSWAP spectrum – will be the reference values of mean overtopping discharge to compare with other calculation tools.

2 A BRIEF DESCRIPTION OF OVERTOPPING PHENOMEN AND CALCULATION METHODS

2.1 Overtopping phenomenon

The overtopping phenomenon occurs when the combination between sea level and waves enable the passage of water over the crest of the structure. Depending on the overtopping volume, the structure stability could be put at risk [5]. The overtopping can be classified in three classes – 'green water', splash and spray –; depending on the way that water passes over the structure crest [2].

The wave overtopping is fundamentally conditioned by waves, sea water level and structure geometry. Waves are conditioned by atmosphere conditions and also by local bathymetry. The Surf similarity parameter (Iribarren Number) allows us to distinguish the type of wave breaking – spilling, plunging, collapsing and surging – [6]. The sea water level has a strong influence on wave overtopping and depends on the local tidal range, weather conditions and in case of river estuaries still depends on the river flow. The structure geometry and characteristics are preponderant in control and reduction of wave overtopping. It should be done an exhaustive study to optimize the structure in order to satisfy the goals for which it was designed (e.g., decrease de slope angle reduces the wave overtopping).

2.2 Empirical formulations

2.2.1 Introduction

Empirical formulations allows us to estimate wave overtopping results from interpolation of results obtained with physical models tests, for a limited set of structures and in some given wave conditions. Overtopping is estimated by structure linear meter, q, being expressed in $m^3/s/m$. Different types of expressions can be used to calculate wave overtopping. The empirical formulations used to calculate the dimensionless mean overtopping discharge, Q, in this study are the exponential (1) [6].

$$\mathbf{Q = a\,exp(-b\,R)} \tag{1}$$

Where a and b are fitted coefficients specific to the front geometry of the structure.

2.2.2 Owen's empirical formulations

Owen's formulation for overtopping, q, of a uniformly permeable simple slope by perpendicular attack can be expressed as

$$\mathbf{q = A\,exp}\left(-\mathbf{B}\,\frac{\frac{\mathbf{R}_c}{T_m\,(g\,H_s)^{0.5}}}{r}\right) T_m\,g\,H_s \tag{2}$$

where A and B are empirical coefficient, T_m is the mean wave period, H_s is the significant wave height at the toe of the structure, r is the is the roughness coefficient, **g** is acceleration due to gravity and R_c is the crest freeboard (the height of the crest wall above still water level). This equation can be used when $R = R_c / (T_m\,(g\,H_s)^{0.5})$ belongs to the interval 0.05–0.30.

To take into account a permeable crest berm, a reduction factor, C_r, is determined as follows:

$$\mathbf{C_r = 3.06\,exp(-1.5\,G_c/H_s)} \tag{3}$$

where G_c is the crest berm width in meters. When $G_c/H_s < 0.75$ assume that $C_r = 1$.

For more details of this formulation see [2].

2.2.3 Methodology in the “Actual Overtopping Manual”

Pullen et al.’s formulation for overtopping, q, of an armoured composite slope with crest berm can be expressed as

$$\frac{q}{\sqrt{gH_{m0}^3}} = 0.2\exp\left(-2.6\ \frac{R_c}{H_{m0}\ \gamma_f\ \gamma_\beta}\right) \tag{4}$$

where H_{m0} is the estimate of the significant wave height form spectral analysis (=4 (m_0) $^{0.5}$), R_c is the crest freeboard, g is the acceleration due to gravity, γ_f is a correction factor for the permeability and roughness of the slope and γ_β is a correction factor for oblique wave attack, if it is perpendicular to the structure γ_β= 1.

Equation (**4**) can be used if $R= R_c/H_{m0}$ belongs to the interval 0.30–2.00 and $\gamma_f \geq 0.5$ [7]. See [4] for more details of this formulation. And to take into account a permeable crest berm, a reduction factor, C_r, is determined with equation (**3**) as in Owen’s formulation.

The calculations were made with the computation tools developed by European project CLASH (Crest Level Assessment of Coastal Structures by Full Scale Monitoring) that are available on-line (http://www.overtopping-manual.com/calculation_tool.html).

2.3 Neuronal networks

The artificial neuronal networks (NN_OVERTOPPING2) developed by DELFT HYDRAULICS in the project CLASH estimates the mean overtopping discharge for different kind of structures. Details of the methodology followed by the development of the prediction tool are described in [8] and [9]. NN_OVERTOPPING can be downloaded from http://www.overtopping-manual.com/download/D41genericpredictionmethod2008.zip or it can be used on-line http://nn-overtopping.deltares.nl/ [10].

This neuronal network is easy to use and has three layers: input layer, hidden layer and output layer. The input layer has 15 input parameters (4 hydraulic parameters and 11 structural parameters). Calculations are done in a hidden layer and results are presented in an output layer that includes mean overtopping discharge, q, and other output values indicating the quantiles of several orders.

2.4 Numerical models

During the last years numerical models of wave overtopping have been developed and due to the continuous increase of computer power their use is becoming increasingly attractive. However, for realistic simulations of wave overtopping, numerical models must be able to simulate all the important hydrodynamic processes involved and should be capable of running sufficient random waves in order to give reasonably consistent results. In maritime structures there are different types of models, such as models based on RANS (Reynolds Average Navier-Stokes) e.g., IH-2VOF [11] or based on NLSW (NonLinear Shallow Water) e.g., AMAZON [11].

In the next chapter the numerical model AMAZON will be shortly described. Based on Mariz et al. [1] study the model IH-2VOF is used here to adjust porous parameters of AMAZON.

3 THE NUMERICAL MODEL AMAZON

The numerical model AMAZON will be briefly described, closely following Mariz et al. [1] and Reis et al. [13]. The model AMAZON is fast enough to be used in a design stage and was developed in Manchester Metropolitan University [11] using C++ programming language. Its formulation is based on the NonLinear Shallow Water (NLSW) equations. These are a simplification of the Navier-Stokes equations by integration in depth and assuming hydrostatic pressure distribution in depth. The model enables simulations of regular and irregular waves not only in one-dimensional version, used in the case study, but also in two-dimensional version. The wave breaking is simulated using the tidal bore concept, in which the mass is conserved but energy is dissipated. It uses a non-reflective wave inlet boundary condition, which is able to remove at the seaward boundary more than 98% of the energy of any waves reflected from the modeled structures. As a consequence, the seaward boundary can be set close to the structure to avoid deep water conditions, where AMAZON has limitations as it is based on solving the NLSW equations. The model AMAZON is capable of flexible computations meshes with diverse forms and variable dimensions. This model can generate as an output the free surface, depth-average velocities and, based on these values, discharge time-series, mean and peak discharges.

AMAZON has been validated in a variety of representative test problems involving steady and unsteady, inviscid and viscous, and subcritical and supercritical flows [11]. It has also been validated and extensively used to study the overtopping of impermeable dikes. However, the numerical model AMAZON has not been systematically used and validated in overtopping studies of permeable structures, as the original version does not have an explicit modulation of porous layers. Since 2007 the Laboratório Nacional de Engenharia Civil (LNEC) in cooperation with Royal Haskoning, UK, have been making some changes in the model in order to become possible to calculate wave overtopping in porous maritime structures and proceed to a systematic validation [1, 14, 15, 16, 17]. To simulate this type of flow the equations of Darcy and Forchheimer were implemented in the model [15].

In the present case study its analysis of a porous structure and overtopping calculation is made using the Forchheimer equations in prototype scale and in a 1:30 scale the overtopping calculation is made by using Darcy and Forchheimer equations and without porous layer. In these cases, to make the calculation in porous layer it is necessary to define the porous layer and calibrate some parameters that affect the flow, namely $\boldsymbol{\alpha}$ and $\boldsymbol{\beta}$ (dimensionless linear and nonlinear friction coefficients) ***IP*** (Interface Permeability, that is the maximum velocity that the water can reach during the exchange between the free-flow (surface). The porosity, $\boldsymbol{n}$, and the representative particle diameter, $\boldsymbol{D_{50}}$, are parameters that can be obtain by characteristics of the structure.

Hu [11] and Reis et al. [14, 15, 16] present a fully described description about the model and their equations.

4 THE CASE STUDY: WEST BREAKWATER OF ALBUFEIRA'S FISHING HARBOR

The structure will be succinctly described closely following Eric et al. [18] and Mariz et al. [1]. The Albufeira's Fishing Harbor is protected by two slope breakwaters, designated Nascent and West. The harbour construction started in 1999 and finished in 2002.

The study cross-section (Fig.1) in the West breakwater has a seaward slope with 3:2 and is developed between +7.0m (Chart Datum – ZH) elevation and -4.0m (ZH) (0.5 m distance to natural seabed). This primary armour is made by two layers of 90 to 120kN rocks and the inner layer is made by 10kN to 30kN rocks. The toe berm has 0.5m thickness and the core are constituted by TOT material. The crest berm in seaward (at +7.0m (ZH) elevation) and the crest berm in leeward (at +6.5m (ZH) elevation) have a 5.9m width. In the central zone of the crest there is a concrete slab with 3.0m width, the crest at +6.5m (ZH) and it is found at +4.0m (ZH) elevation. It should be noted that the blocks of the primary layer have extremely high packing density.

A field campaign was planned (Fig.2) in the last winter but there were no sea conditions for its execution. The campaign's objective was to measure the overtopping discharge and the maritime agitation that attacks the structure [19].

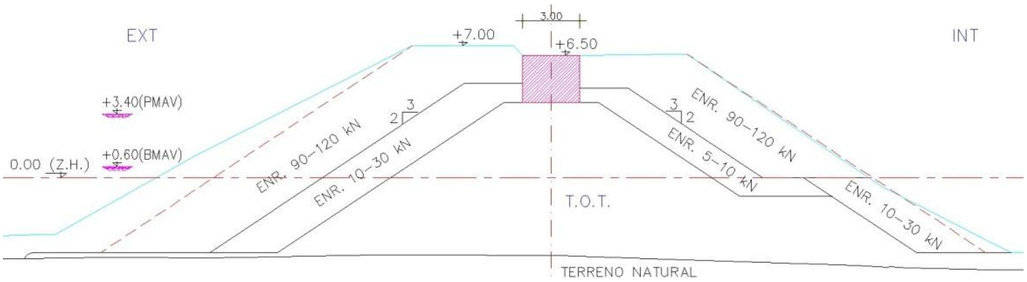


Fig.1. Cross-section in study of West breakwater of Albufeira's Fishing Harbor.

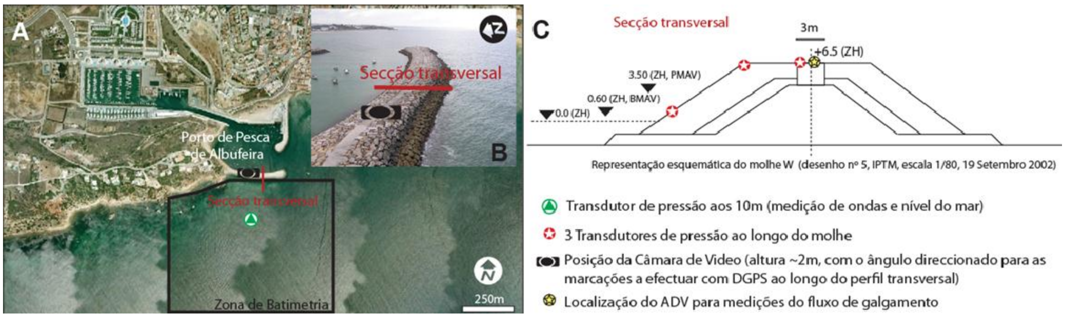


Fig.2. (A) Aerial Image of Albufeira’s Fishing Harbor (adapted from Google Earth, 2006) showing the zone where the works will be performed of bathymetry, video camera’s location and pressure transducer to ~10m depth; (B) West breakwater of Albufeira’s Fishing Harbor where will be performed the field campaigns with section in study indicated; (C) Schematic representation of the breakwater section and equipment positioning (PTs e ADV) [19].

Based on the bathymetry of the local conditions, the tidal range, the wave field and also the cross-section’s characteristics of West breakwater of Albufeira’s Fishing Harbor, preliminary calculations of mean overtopping discharge were done, based on empirical calculation tools in order to better define the field campaign conditions [18].

In this study a sensitivity analysis about the parameters of the numerical model AMAZON was done (Section 5). Two cases with clear occurrence of overtopping, (with) regular waves with wave period of T= 10s and T= 12s and a wave height H= 4m, and a sea water level of +3.5 m (ZH) - that is nearly the high water level (HWL) in Albufeira, according to tide tables 2011 of Portuguese Hydrographic Institute - were selected. Afterwards the parameters were adjusted with another numerical model, IH-2VOF, [1] because there was not any data field available. Finally the results obtained with AMAZON were compared with empirical formulations and neuronal networks.

5 MEAN OVERTOPPING DISCHARGE

5.1 Numerical model AMAZON

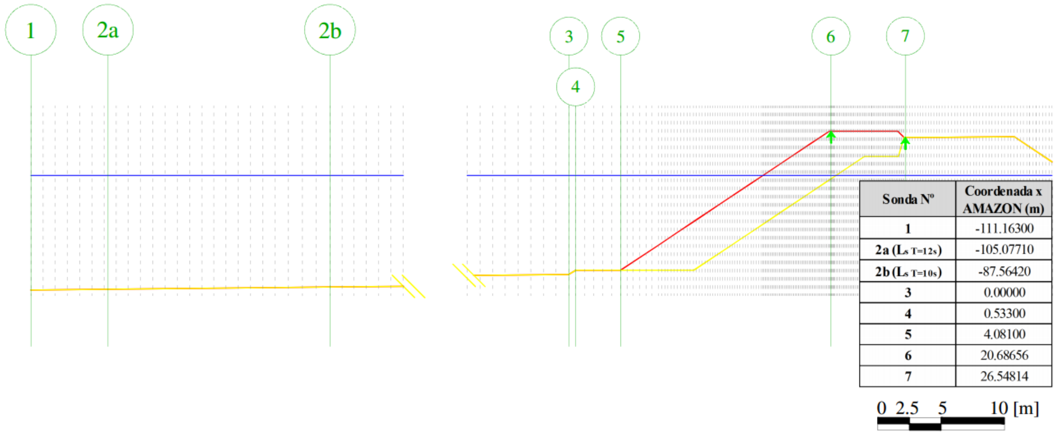
5.1.1 Sensitivity analysis with regular waves

In order to make the sensitivity analysis of AMAZON’s parameters that characterize the porous layer, the model was used in prototype scale and in reduced scale, 1:30, to some selected cases (+3.5m (ZH), T= 10s and T= 12s, H= 4m) with two different considerations of porous layer.

As it was previously mentioned, the AMAZON is based on the NonLinear Shalow Water (NLSW) equations. Thus, initially it was weighted if the consideration of shallow water for the case study was correct. It was assumed that the offshore wave period (T_0) would be equal to the wave period in the toe of the structure (T). For this purpose, through linear wave theory, it was estimated the wavelength (L) in the toe of the structure in the cross-section in analysis (located at depth d_s= 7.82m). It was verified that the case study is in intermediate water depth ($L_{T=10s}$ = 82.96m and $L_{\ T=12s}$= 101.24m), near shallow water, since 4.15 m= $L_{\ T=10s}$/20< 7.82m< $L_{0\ T=10s}$/2= 78.07m and 5.06m= $L_{\ T=12s}$/20< 7.82m< $L_{0\ T=12s}$/2= 112.42m.Thereafter, it was checked the value of d/L_o is in the range 0.016 - 0.19, stated in literature as the range for which good results are obtained with LNSW models [19], being d the depth in the inlet model boundary (d= 9.05 m) and L_o the wavelength in deep water ($L_{o\ T=10s}$ = 156.13m and $L_{o\ T=12s}$ = 224.83m).The estimated value was the d/L_o= 0.04. Consequently significant errors in numerical calculation due to shallow water approximation are not expected.

It was followed the recommendation purposed in [20], in order to optimized the results, thus the inlet model boundary should be located in circa one wavelength, L_s, of the toe of the structure, being the wavelength in shallow water ($L_{s\ T=10s}$= 87.56m and $L_{s\ T=12s}$= 105.08m). In that case it was decided to place the inlet model frontier slightly seaward, at the point coincident with the waves measurements in prototype with a pressure transducer placed about 10m deep and approximately 111m of the foot of the structure (-5.55m (ZH)). The outlet model boundary is a total absorption boundary and was placed to 8.7m downstream of concrete structure of the breakwater.

The domain of the calculations has an extension of 150m length and a total of 327 cells used. It was defined a non-uniform calculation mesh throughout the entire profile (Fig.3). In the deepest zone of domain, that is, in the front implantation local of the breakwater cells are 1m length. From the breakwater zone till the overtopping measurement zone, in concrete structure at breakwater, the size ranges between 0.05m and 0.1m. This discretization is based on the experience gained in previous studies of convergence of the model and it is thin enough to ensure the required accuracy for the sensitivity analyses and large enough to reduce the computational time calculation to a minimum.



Sonda Nº	Coordenada x AMAZON (m)
1	-111.16300
2a ($L_{s\ T=12s}$)	-105.07710
2b ($L_{s\ T=10s}$)	-87.56420
3	0.00000
4	0.53300
5	4.08100
6	20.68656
7	26.54814

Fig.3. Schematic representation of computational of the discretization mesh used at breakwater only with a single porous layer (red), impermeable foundation and concrete structure (yellow), steal water level (blue) and measurements locations (green) and respective coordinates, in prototype scale.

The geometrical characteristics of the foundations in front of the breakwater and the structure's surroundings till the final of the walkway in concrete were truly represented in AMAZON. The foundation and the walkway in concrete were modeled as impermeable and without friction. AMAZON could only represent a porous layer. The sensitivity analysis studied two different cases. In the first one, the primary rock layer was made by 90 to 120kN rocks (Fig.1), with D_{50}= 1.6m based on mass of the blocks and the inner layer (made by 10 to 30kN rocks) and the core behave in a totally impermeable material. In the second case, the primary rock layer was made by 90 to 120kN rocks and the inner layer (made by 10 to 30kN rocks) (Fig.1), with D_{50}= 1.5m based on mass of the blocks and the core behave in a totally impermeable material. The second case was only studied in a prototype scale and was concluded that the parameters lost its importance in overtopping influence.

The methodology used in the sensitivity analysis of the parameters of the porous layer in AMAZON started with the definition of base parameter values n, α, β e IP. For α and β parameters recommended values in literature can be found [21]: for α values range between 1100 and 1800 and for β range between 0.55 and 1.10. The porosity values, n, resulted from a visual analysis of the primary layer and from the profile information: varied between 0.30, 0.35 and 0.40 due to an extremely high packing density.

For the IP parameter, some authors (e.g. [22]) consider that the value of the hydraulic gradient at the interface between two layers is less than 1, which is equivalent to considering a unique value of IP in the beginning that was determined from D_{50}, n, α e β values [14]. In AMAZON, IP is considered as an input value that should be calibrated. In the considered case, the IP value ranged between 0.1m/s and the value for which no longer is observed overtopping of the probe 7 (Fig.3) or until reaching the maximum value calculated based on IP [14].

Seven measurement sections were used in the numerical model (Fig.3): two located seaward of the structure (probes 1 and 2), three located in the toe of the structure (probes 3 to 5) and the remnant in its crest (probes 6 and 7). The probes 6 and 7, which are located on the walkway in concrete, were used to calculate the overtopped discharge at two points. The discharge in probe 7 will be displayed as a result of the sensitivity analysis of the model parameters. Each sensitivity analysis run lasts for approximately 100 waves.

In order to illustrate the described methodology, above is presented a preliminary sensitivity analysis of parameters ***n***, ***α***, ***β*** e ***IP*** of the model AMAZON (Fig.4). As the simulations with a wave period ***T***= 10s showed that, in prototype scale, the parameter ***α*** does not lead to significant changes in mean overtopping discharge (probe 7 of Fig.3) it will be presented the dependence of this discharge with de variation of the other parameters to a wave period ***T***= 12s.

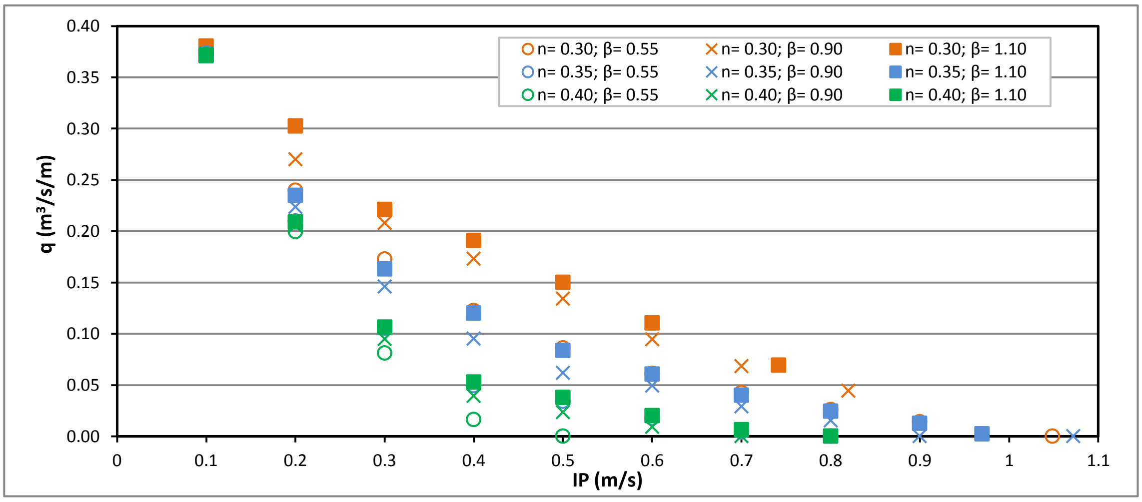


Fig.4. Mean overtopping discharge, ***q***, with parameters variation ***n***, ***β*** e ***IP*** in the porous layer, for ***α***= 1500 and ***T***= 12s.

Analyzing the results obtained, for the same ***IP*** value, it can be concluded that the variation of ***n*** is the one that has the most influence over the mean overtopping discharge per unit meter and ***β*** value seems to have the least influence. ***IP*** variance is also relevant in the value of overtopping, for any value of n and ***β***. For higher ***IP*** values, for which is obtained the lowest overtopping values (near zero), the influence is less significant in the others parameters and for ***IP***= 0.1m/s seems to be no impact or variation on ***n***, either ***β***, which may be due to saturation of the porous layer.

In the reduced scale as in prototype scale it was verified that numerical model AMAZON can be used also for reduced scale, 1:30, because in this scale and using Froude's similarity and the shallow water depth is also valid. It was used a similar mesh in the model.

The structure was simulated with Darcy and Forchheimer equations and considered all as impermeable (Fig.5) in 1:30.

Analyzing the obtained results of mean overtopping discharge it is showed that using Darcy equations in reduced scale gives higher values than Forchheimer and gives lower values than considering all the structure as impermeable. The results demonstrate that Darcy formulation is not valid to 1:30 scale because the flow in porous layer is turbulent and the porous layer is almost saturated in the simulation time. In a reduced scale, ***α*** value influences the mean overtopping discharge more or less the same as ***β*** value.

Comparing prototype and reduced scales results was observed that the prototype gives, in general, higher values of mean overtopping discharge and the significant wave height is also higher. The Froude similarity could not be the best way of "scaling" ***IP*** values.

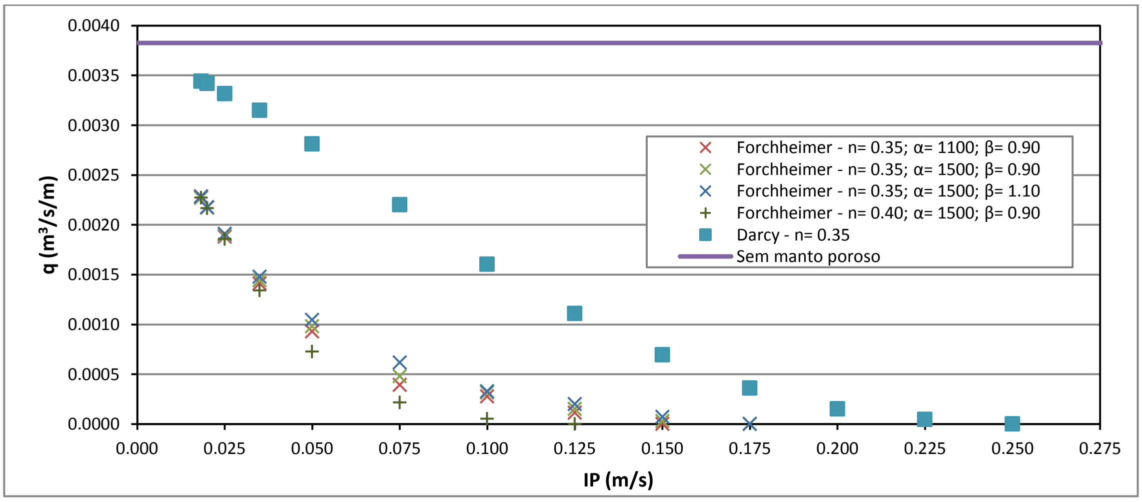


Fig.5. Mean overtopping discharge, ***q***, with parameters variation ***n***, ***α***, ***β*** e ***IP*** in the porous layer, for ***T***= 2.19s, in reduced scale.

5.1.2 Adjustment of parameters and analysis for the conditions of irregular waves

Since it was not possible to calibrate AMAZON due to the nonexistence of data field, it was attempted to adjust the parameters of the Forchheimer equations in a prototype scale. The numerical model IH-2VOF allows the modeling of each structure layer is based on RANS equations and it is not necessary to define the ***IP*** value. Comparing the results obtained in the two numerical models, having the same porosity, the ***IP*** value should be of the order of 0.30 to 0.40 m/s as is suggested in Mariz et al. [1]. Then, there were chosen de medium values within the recommended ones for each parameter, so ***n***= 0.35, ***IP***= 0.35, ***α***= 1500 and ***β***= 0.90. Then it was calculated the mean overtopping discharge, ***q***, using irregular waves generated by JONSWAP spectrum (Table.1) with 1000 waves.

Table.1. Mean overtopping discharge, ***q***, and wave height, ***H***, and wave period, ***T***, in probe 3 of Fig.3 for waves generated with JONSWAP spectrum, ***n***= ***IP***= 0.35, ***α***= 1500 e ***β***= 0.9 in AMAZON in prototype scale.

T_p AMAZON (s)	H_s AMAZON (m)	q AMAZON (l/s/m)	H_s (m)	H_m (m)	$H_{1/10}$ (m)	$H_{\text{máx}}$ (m)	T_m (s)	T_s (s)	$T_{\text{máx}}$ (s)	$T_{1/3}$ (s)
12	**4**	**37.097**	2.969	2.049	3.392	4.556	9.867	12.112	18.300	9.867
	3	**6.481**	2.438	1.674	2.878	3.856	10.068	11.742	18.100	10.068
	2	**0.287**	1.844	1.217	2.291	2.990	10.068	11.506	17.700	10.068
	1	**0.000**	0.940	0.608	1.223	1.745	10.746	12.171	16.000	10.746
10	**4**	**15.994**	2.600	1.704	3.062	3.845	7.673	9.335	15.400	7.673
	3	**1.231**	2.131	1.337	2.509	3.167	7.226	8.741	15.000	7.226
	2	**0.000**	1.526	0.939	1.901	2.236	7.200	8.630	14.800	7.200

5.2 Comparison between the numerical model AMAZON and other formulation tools

It was calculated the mean overtopping discharge using empirical formulations in a prototype and in a reduced scale (1:30) using Froude similarity.. The Fig.6 represents the comparison between AMAZON and other calculation tools using the wave periods and heights displayed in Table.1 (probe 3 of Fig.3).

The results show that the better empirical formulation to estimate the mean overtopping discharge is Owen's formulation [2, 3] in the case study. This can easily be explained by the fact that there isn't any similar case to Albufeira's breakwater in study in the neuronal networks data base. In the methodology purposed in "actual overtopping manual" [4] the wave period do not affect the results. Notice that the numerical modal used was only adjusted based on other numerical model and was not yet calibrated.

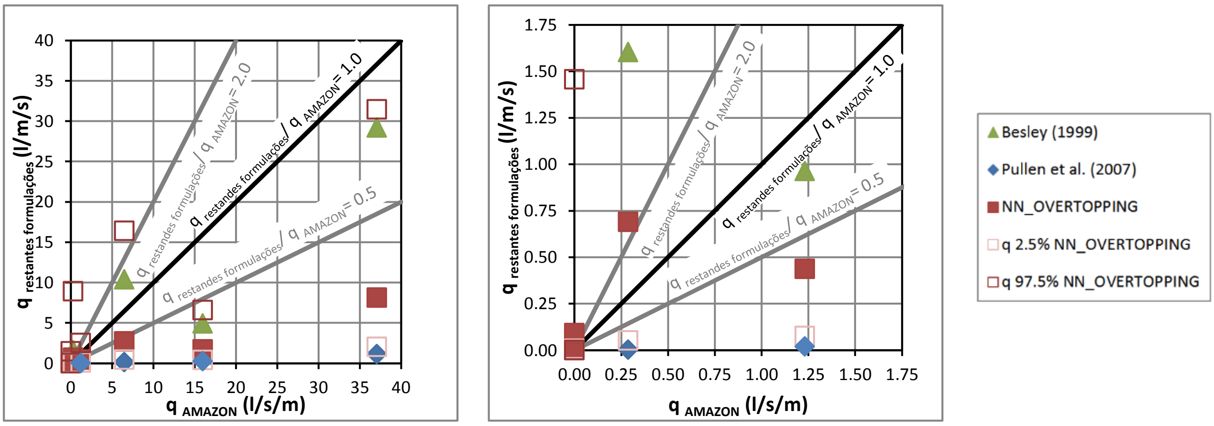


Fig.6. Comparison between mean overtopping discharge, ***q***, obtained with AMAZON and with empirical formulations and neuronal networks (NN_OVERTOPPING2).

6 CONCLUSIONS

This study was focused in the overtopping phenomenon calculated by two empirical formulations, neuronal networks and the numerical model AMAZON applied to the case study: West breakwater of Albufeira's Fishing Harbor.

Firstly it was tested the parameters' influence in a sensitivity analysis, in the numerical model AMAZON, considering only the primary armour layer in a prototype scale with Forchheimer equation. It was verified that the porosity, ***n***, influences the most the mean overtopping discharge when it is compared with the remaining parameters. The interface permeability, ***IP***, has also an important influence in wave overtopping and ***α*** and ***β*** are parameters that do not cause significant changes in mean overtopping discharge value. Then, it was verified that the parameters have more influence in the results when it was considered only the primary layer as porous layer in AMAZON.

In the numerical model AMAZON it was also done a sensitivity analysis of parameters of porous equations (Darcy and Forchheimer) in a reduced scale, 1:30. The parameter influence is almost the same as in prototype scale except ***α*** value that has more influence in a reduced scale. It was also verified that the Darcy equation in the case study is not valid because the flow in porous layer is turbulent.

In order to conclude, it is important check the conditions of applicability of each formulation and the numerical model. It was verified that Owen's empirical formulation is the one that gives results with less differences to the results of AMAZON. Note that the parameters were only adjusted with other numerical model, IH-2VOF [1] and to validate is suggested approximate values in measures and in the numerical model, firstly changing ***n*** and ***IP*** values and then ***α*** and ***β*** values.

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